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Numerical Investigation of the Bedding Factor of Concrete Pipes under Deep Soil Fill

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Abstract **-** The Indirect Design Method is often used to design buried concrete pipes. This method is based on linking the required strength of the buried concrete pipe to the laboratory strength of the pipe by using an empirical factor called the bedding factor. Hence, the bedding factor is key in the Indirect Design Method. However, a thorough review of the literature showed that the bedding factor has not received signification attention in previous studies. This study therefore reports the preliminary results of ongoing research investigating the bedding factors and the behaviour of concrete pipes under deep soil fill using validated numerical modelling. The results showed that the AASHTO bedding factors for type 2, type 3 and type 4 AASHTO installations are conservative, while the bedding factor is unsafe for pipes buried in type 1 installation with a backfill height of less than 2.4 m. Comparing the results of the present study with the British Standard bedding factors showed that these factors are overly conservative. Hence, both design standards should be updated to enhance the robustness of the design approaches and make the design of concrete pipes more economic.

Keywords**:** The Indirect Design Method, The bedding factor, Reinforced Concrete pipes, AASHTO, BS.

Nomenclature

SW95	well-graded sand with a degree of compaction of 95% of the Standard Proctor test
SW90	well-graded sand with a degree of compaction of 90% of the Standard Proctor test
SW85	well-graded sand with a degree of compaction of 85% of the Standard Proctor test
ML95	sandy silt with a degree of compaction of 95% of the Standard Proctor test
ML90	sandy silt with a degree of compaction of 90% of the Standard Proctor test
H	backfill height
E	the modulus of elasticity of the concrete
υ	Poisson ratio
γ	unit weight of the soil
c'	cohesion of the soil
ϕ'	angle of internal friction of the soil
K	modulus number
R_f	failure ratio
n	modulus exponent
VAF	the vertical arching factor
r	the radius of the pipe measured to the centre of the pipe wall
M	the bending moment of the buried pipe predicted from the finite element modelling

1. Introduction

The Indirect Design Method is often used to design reinforced concrete pipes [1]. The idea of this method is based on linking the required strength of the concrete pipe to the laboratory strength of the pipe by using an empirical factor called the bedding factor. Hence, the bedding factor is the key in the Indirect Design Method. The laboratory capacity of the pipe can be found by using the three-edge bearing test; in this test the pipe is supported at the invert only and loaded by a line load at the crown [1]. The force required to cause a crack width of 0.254 mm is taken as the pipe capacity [1].

Despite the importance of this topic in the practical application of rigid pipeline design, the literature lacks studies on the bedding factor of concrete pipes under deep soil fill, where the majority of the previous studies on concrete pipes have focused on the soil pressure around the pipe, the tensile stress in the pipe wall and the soil arching. Pettibone and Howard [2] investigated the effect of the soil stiffness on the earth pressure developed around a 0.6 m outside diameter pipe using laboratory based test in a soil box. The length, width and height of the box were 2.13 m, 1.83 m and 2.13 m, respectively. Pettibone and Howard [2] found that the quality of the soil in the bedding and haunch zones significantly affected the pressure developed around the pipe. Wong et al. [3] investigated the short-term and long-term earth pressure on concrete pipes buried in the AASHTO type 4 installation condition (i.e. poor support was provided to the pipe in the haunch zone). Four pipes were tested with different trench configurations. The inner diameters of the pipes ranged from 0.6 to 0.9 m. Wong et al. [3] found that the earth pressure increases with time due to the soil settlement under repeated activities of traffic and snow loads. Motahari and Abolmaali [4] and Abolmaali and Kararam [5] investigated the impact of the bedding thickness and bedding soil type on the maximum tensile stress in the concrete pipe wall under deep soil fill using three-dimensional finite element method. A maximum backfill height of 30 m was considered in these studies. They found that increasing the bedding thickness while decreasing the compaction level of the bedding soil decreased the tensile stress at the invert of the pipe. Kang et al. [6] studied the effect of the installation condition on the soil pressure around the pipe and the vertical and horizontal soil arching using a two-dimensional finite element model. They found that the vertical arching factor decreased as the backfill height above the pipe increased. Allard and El Naggar [7] studied the effect of the trench width, trench inclination, backfill height and surrounding soil stiffness on the response of a rigid pipe using a two-dimensional finite element model. They found that the vertical arching factor decreased as the backfill height above the pipe increased or the trench width decreased. Furthermore, they found that the bending moment, deflection, axial thrust and shear forces developed in the pipe wall decreased as the pipe installation quality increased (i.e. the stiffness of the soil around the pipe increased). MacDougall et al. [8] investigated the bedding factor of a 0.6 m diameter concrete pipe under deep soil fill using laboratory biaxial cell. The length, width and height of the cell were 2 m, 2m and 1.6 m, respectively. The maximum applied uniform pressure on the surface was 700 kPa. The pipe was installed using the AASHTO type 2 standard installation (i.e. good support was provided for the pipe in the haunch zone). They found that the bedding factor of AASHTO type 2 installation is conservative.

As shown in this brief review, the majority of previous studies did not focus on the bedding factor of the concrete pipe, where only one study has investigated the bedding factor under deep soil fill and with limited conditions (neglected the effect of the pipe diameter and installation conditions). This study therefore presents the preliminary results of an ongoing study on the response of concrete pipes and the bedding factor under deep soil fill using validated numerical modelling. The study aims to fill the gap in knowledge in the literature about the effect of the installation condition on the bedding factor and the robustness of the current bedding factor values adopted in the AASHTO and BS design standard.

2. Statement of the Problem

The present study deals with a concrete pipe with an inside diameter of 1.2 m and a thickness of 0.144 m buried in an embankment condition under the effect of deep soil fill. The effect of the backfill height and the installation condition are discussed in this paper. The four AASHTO installation types (type 1, type 2, type 3 and type 4) [9] are considered in the numerical modelling. Figure 1 shows the soil condition around the pipe for the four installation types. The details of the numerical modelling are discussed in the next section.

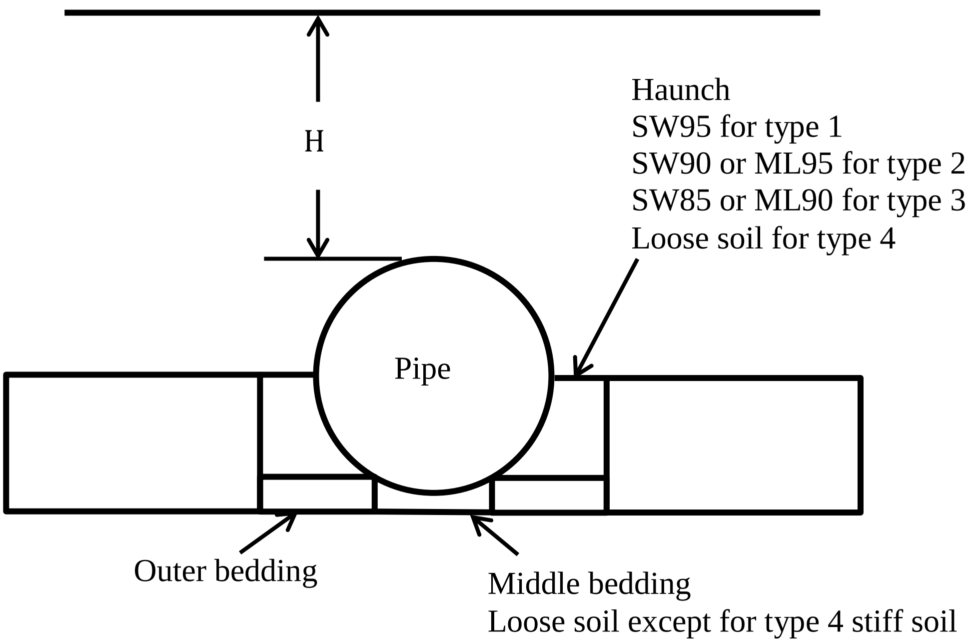


Fig. 1: AASHTO installation types [9] (Note: SW is well-graded sand or gravelly sand; ML is sandy silt)

3. Numerical Modelling Details

The three-dimensional numerical model used in this study was validated using laboratory and full scale results from the literature. The model was developed using MIDAS GTS/NX software. Details of the numerical model validation can be found elsewhere [10]. The length, width and height of the numerical model were equal to 6 m, 5 m and 5 m, respectively. Four noded tetrahedron solid elements have been used to model the soil, while three noded triangular shell elements were used to model the pipe. A trench with a width of 4.0 m and height of 2.39 m was considered in the modelling to use finer elements around the pipe to enhance the accuracy of the numerical modelling. The average element size was 0.15 m for the pipe, 0.15 m for the trench and 0.5 m for the surrounding soil. The numerical model is show in Figure 2.

The hyperbolic Duncan-Chang soil model [11] was used to model the in situ soil, bedding soil and backfill soil. This model was used because it is capable of simulating the dependency of the soil stiffness on the stress level. Previous studies have shown that simulating the dependency of soil stiffness on the stress level produces more accurate results in soil-pipe interaction modelling [6, 12, 13, 14]. A linear elastic model was used to model the pipe. The modulus of elasticity (E) and Poisson ratio (υ) of the pipe were taken as 38451 MPa and 0.2, respectively [15].

The bedding soil was simulated using well graded sandy soil with a degree of compaction of 90% of the standard Proctor density (SW90). This was done to simulate the worst case scenario [3]. The four AASHTO installation types (type 1, type 2, type3 and type 4) have been considered in this study by changing the soil at the haunch zone following the AASHTO recommendation for each type. SW95 soil was used for AASHTO type 1, SW90 soil was used for AASHTO type 2, ML90 was used to simulate AASHTO type 3 and ML49 was used to simulate AASHTO type 4 [9]. The soil parameters of all of these soils were taken from the literature [16] and are shown in Table 1.

Three steps were performed to model the installation of the pipe and the deep soil fill:

Step 1: The initial earth pressure of the soil beneath the pipe were calculated using a coefficient of lateral earth pressure of 1.0 [17].

Step 2: The bedding soil, pipe and soil above the pipe were added and the initial earth pressures were calculated using a coefficient of lateral earth pressure of 1.0 [17].

Step 3: A uniformly distributed load was applied on the top of the model to simulate the deep soil fill. This technique was used successfully by other researchers to reduce the analysis time [6, 18, 19].

Table 1: Soil Properties used in the finite element modelling [16]

Property	SW95	SW90	ML90	ML49
γ (kN/m3)	22.07	20.99	18.84	10.40
υ	0.3	0.3	0.3	0.3
c'(kPa)	1	1	24	1
ϕ'(°)	48	42	32	23
K	950	640	200	16
Rf	0.7	0.75	0.89	0.55
n	0.6	0.43	0.26	0.95

Note: γ is the density of the soil; υ is the Poisson's ratio; c' is the cohesion of the soil; $\phi'$is the angle of internal friction; K and n are the hyperbolic parameters for stiffness modulus and Rf is the failure ratio.

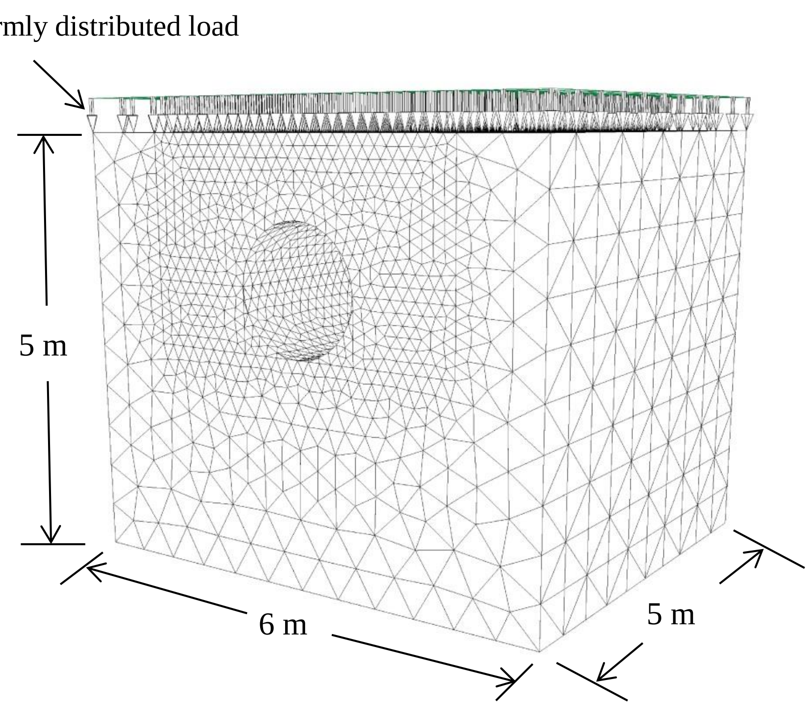


Fig. 2: Finite element mesh of the problem

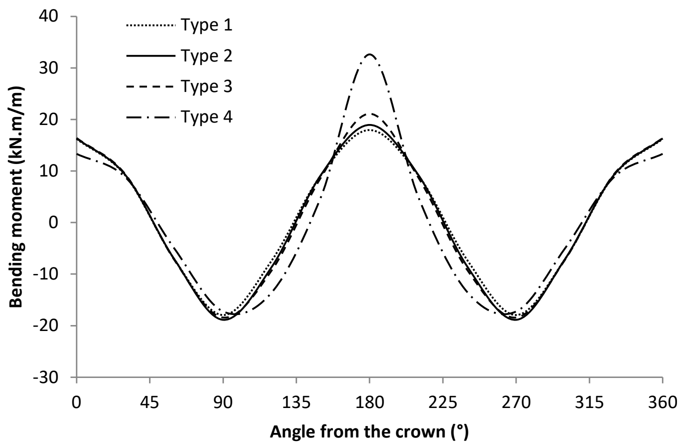
4. Results

This section summarizes the results obtained from the finite element modelling. The section has been divided to two subsections covering the bending moments in the pipe wall and the bedding factors in relation to backfill height and different installation conditions.

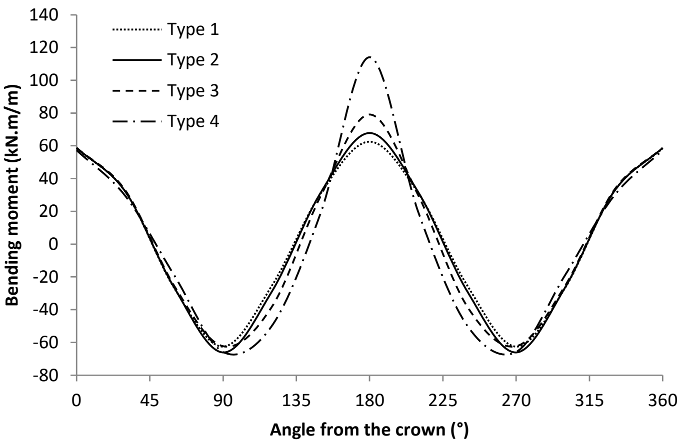
4.1. Bending Moment

Figure 3 shows the effect of the installation type on the bending moment developed around the pipe. It can be seen that the bending moment at the invert of the pipe increases as the installation quality decreases, for example changing the installation type from 1 to 4 increases the bending moment by 82%. This is due concentration of the reaction forces at the invert of the pipe as the quality of the soil in the haunch zone decreases [2]. However, it can be seen that there is no significant increase in the bending moment at the invert of the pipe as the installation type changes from type 1 to type 2, where the percentage increase is equal to 5.6% and 8.5 % for the 10 m and 39 m soil fill, respectively. The Figure also shows that the installation type does not significantly affect the bending moment developed at the crown of the pipe (the maximum percentage difference is 18%).

Figure 4 shows the effect of the backfill height on the maximum bending moment for all of the installation conditions considered. It can be seen that increasing the backfill height linearly increases the maximum bending moment for all of the installation types.



(a) 10 m



(b) 39 m

Fig. 3: Bending moment around the pipe

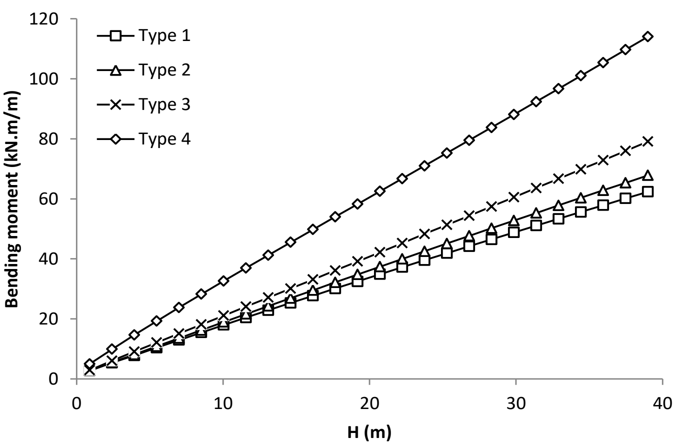


Fig. 4: Effect of backfill height on the developed maximum bending moment

4.2. Bedding Factor

As discussed in the introduction, the bedding factor is the ratio of the actual capacity of the pipe in the laboratory to the capacity of the buried pipe in the field. Hence, it can be obtained by dividing the maximum bending moment developed in the pipe wall in the laboratory test (obtained from a three-edge bearing test) to the maximum bending moment developed in the pipe wall in the field as shown in Equation 1 [20].

$$BF = \frac{0.318\, VAF\, H\, \gamma\, r^2}{M} \tag{1}$$

Where, VAF is the vertical arching factor (VAF = 1.35 for type 1, 1.4 for type 2 and type 3 and 1.45 for type 4 [9]), H is the backfill height, γ is the unit weight of the soil, r is the radius of the pipe measured to the centre of the pipe wall and M is the bending moment of the buried pipe predicted from the finite element modelling.

Figure 5 shows the calculated bedding factor. It can be seen that the bedding factor increases as the backfill height increases. This is due to a decrease in the soil arching as the backfill height increases, which in turn reduces the field bending moment in comparison with the AASHTO constant vertical arching factor used in calculating the force on the pipe.

The ratio of the calculated bedding factor to the recommended bedding factor values in the AASHTO and British Standard (BS) has been calculated and are shown in Figures 6 and 7, respectively, to investigate the robustness of the current design standards. It should be noted here that the bedding factor value in the AASHTO installation depends on the diameter of the pipe and the installation condition, while in the BS it depends only on the installation condition. Table 2 shows the current bedding factors adopted in the AASHTO standard (for the 1.2 m pipe) [9] and the BS [21].

Figure 6 shows that the AASHTO bedding factors are conservative (i.e. a ratio higher than 1) except for the backfill height less than 2.4 m with the type 1 installation condition. Figure 7 shows that the BS bedding factors are more conservative than the AASHTO bedding factors, where the ratio ranges from 1.34 to 3.08, while for the AASHTO it ranges from 0.75 to 2.03. Hence, it can be concluded that both design standards provide an uneconomical design of concrete pipes.

Table 2: AASHTO and BS bedding factor values [9, 21]

Installation type	AASHTO	BS
Type 1	3.94	2.2
Type 2	2.87	1.9
Type 3	2.27	1.5
Type 4	1.7	1.1

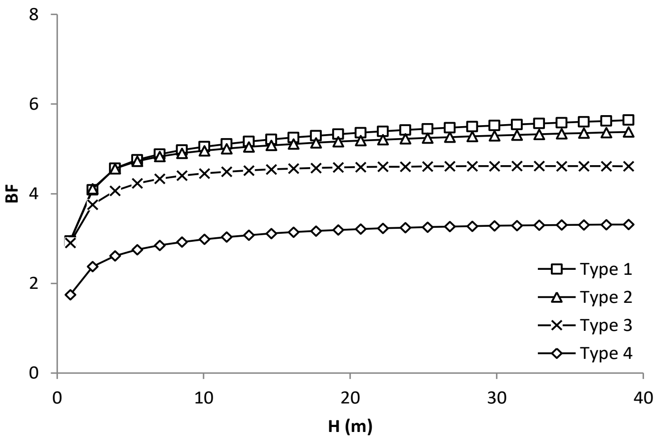


Fig. 5: Effect of backfill height and installation condition on the bedding factor

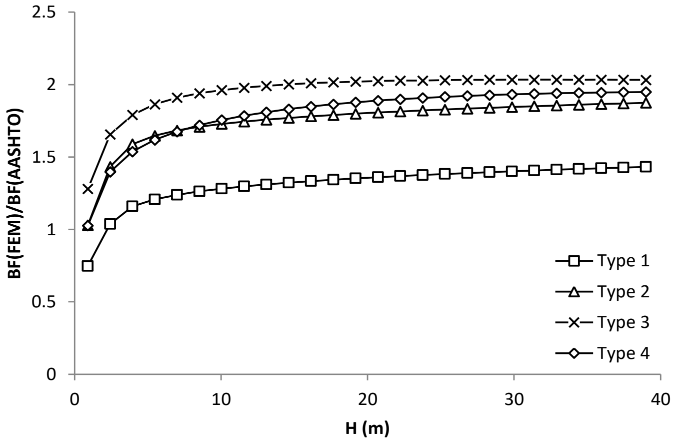


Fig. 6: Ratio of bedding factors obtained from the numerical modelling and the AASHTO standard values for different installation conditions

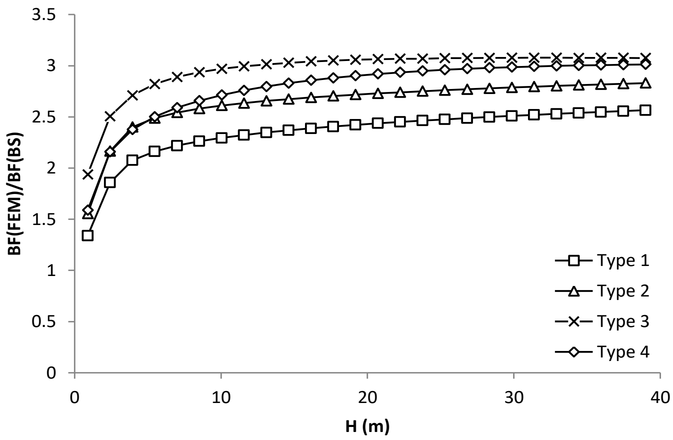


Fig. 7: Ratio of bedding factors obtained from the numerical modelling and the BS values for different installation conditions

5. Conclusions

This study has investigated the effect of backfill height and installation condition on the bending moment developed in a 1.2 m concrete pipe buried in an embankment installation condition. The four AASHTO installation types have been considered in the analysis. In addition, the maximum bending moment obtained from the numerical modelling has been used to calculate the bedding factor. The following conclusions can be drawn from the study:

1- The maximum bending moment in the pipe increased by 82% as the installation type changes from type 1 to type 4.
2- The results showed that the installation condition does not significantly affect the bending moment developed at the crown of the pipe, where the maximum percentage difference was 18%.
3- Changing the installation type from 1 to 2 does not significantly affect the maximum bending moment.
4- The bedding factor value is significantly affected by the installation condition and the backfill height.
5- The AASHTO standard and BS bedding factors are conservative. An update to the current bedding factor is required in both standards to achieve a more robust and economical concrete pipe design.

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